EFFECT OF REWETTING ON SELECTED PHYSICAL PROPERTIES OF ‘ASONTEM’ COWPEA VARIETY

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ABSTRACT

The physical properties relevant to the design and manufacture of handling, storage and processing equipment were determined under varying grain moisture content for ‘*Asontem’* cowpea variety between 8.07%wb and 22.54%wb. The length, width, thickness, geometric mean diameter, surface area, volume, 1000 grain mass, bulk density, true density, filling angle of repose and the static coefficient of friction increased with increasing moisture content during rewetting. In the moisture content range of 8.07% w.b. to 22.54% w.b., the length, width and thickness increased non-linearly from 7.00 to 7.29mm, 6.27 to 6.33mm and 4.54 to 4.69mm, respectively. The geometric mean diameter, surface area, volume and 1000 grain mass increased from 5.83 to 5.99mm, 107.03 to 113.09mm^2, 104.45 to 113.45mm^3 and 120.15 to 130.58g, respectively while bulk density and true density decreased non-linearly from 752.95 to 682.93kg/m^3 and 1219.90 to 1161.39 kg/m^3, respectively. The filling angle of repose increased non-linearly from 27.81 to 32.31 while the coefficient of static friction also increased non-linearly from 0.29 to 0.41, 0.31 to 0.45 and 0.25 to 0.32 for plywood, mild steel and rubber respectively. Mild steel offered the highest coefficient of friction followed closely by plywood then rubber.

Keywords: *asontem* cowpea, physical properties, angle of repose, coefficient of static friction.

INTRODUCTION

Cowpea (*Vigna unguiculata* L. Walp.), an annual legume, is also commonly referred to as southern pea, blackeye pea, crowder pea, lubia, niebe, coupe or frijole. Cowpea originated in Africa and is widely grown in Africa, Latin America, Southeast Asia and in the southern United States. It is chiefly used as a grain crop, for animal fodder or as a vegetable. The history of cowpea dates to ancient West African cereal farming, five to six thousand years ago, where it was closely associated with the cultivation of sorghum and pearl millet (Davis *et al*., 1991).

‘Asontem’ is adapted to all five major agro-ecological zones in Ghana and as such can flourish in these zones, but it is more popular in the coastal savannahs for both the major and minor seasons. Due to its adaptability and early maturity, ‘*Asontem’* is currently the most widely cultivated improved cowpea variety in Ghana occupying 44% of area planted to improved cowpea in the Guinea savannah zone (Abatania *et al.*, 2000 cited in Asafo-Adjei *et al*., 2005).

According to Kabas *et al*. (2007), the function of many types of fruit processing machines is influenced decisively by the size and shape of the fruit participating, and so in order to study a given process the fruit should be described accurately. Based on this, several researchers have determined the physical and mechanical properties of different agricultural products as a function of moisture content in order to provide essential data for the design of equipment for the handling, conveying, separation, drying, aeration, storing and processing of seeds. These include researchers such as Baryeh (2000) for bambara groundnuts; Bart-Plange *et al*. (2005) for maize; Varnamkhasti *et al.* (2007) for rice and Kiliçkan *et al.* (2010) for spinach seed.

Principal axial dimensions of grains are useful in selecting sieve separators and in calculating grinding power during size reduction. They can also be used to calculate surface area and volume of grains, which are important during modeling of grain drying, aeration, heating, and cooling. Bulk density, true density, and porosity play an important role in many applications such as design of silos and storage bins, separation from undesirable materials, sorting and grading, and maturity evaluation (Tavakoli *et al*., 2009).

Post-harvest operations for cowpea generally consist of cleaning, sorting and grading. In Ghana these operations are often done on small-scale and manually. Currently, the seeds are extracted manually by breaking the pod and removing the seeds. These methods of handling and processing seeds are not only time and energy consuming, but also inefficient as they come with some chaff. Lack of standard principles for grading, packaging and consumers preferences has led to problems in storage and marketing. The physical properties of some varieties of cowpeas in Ghana have been found, such as that for ‘*asetenapa*’ and ‘*adom*’. However, no work appears to have been done on the physical properties of ‘*asontem*’. This study evaluated various physical properties of the ‘*asontem*’ cowpea variety for different moisture contents during rewetting, since these properties are needed for the design of equipment for handling and other post-harvest operations.

The objective of this study was to determine the effect of rewetting on size and shape properties, 1000 grain mass, bulk density, true density, angle of repose and coefficient of static friction for the ‘*asontem*’ variety.

MATERIALS AND METHODS

Sample preparation

The '*Asontem'* cowpea variety was obtained from the Crops Research Institute of the Council for Scientific and Industrial Research (CSIR) at Fumesua, Kumasi. The grains were already clean from chaff and other foreign materials. They were acquired as part of grains from the 2010 major harvesting season. The initial moisture content of the grains was determined using the standard oven method and was found to be 8.07% (wb).

The beans were then conditioned to three other moisture content levels in the range of 11-23%wb by adding calculated amount of distilled water, sealing in low density polythene bags and stored in a refrigerator at a temperature of 5 degrees for 72 hours. This was done to create a favourable environment for the absorption of water by the grains and also to prevent the action of microbes on the moist seeds. Before starting a test, the required quantities of the samples were taken out of the refrigerator and allowed to warm up to the room temperature for about 2 hours (Singh and Goswami, 1996). The desired moisture content were obtained by adding calculated amounts of distilled water to the samples using equation (1).

$$Q = \frac{W_i(M_f - M_i)}{100 - M_f} \quad (1)$$

Where

Q = mass of water to be added (g)
W_i = initial mass of sample to be conditioned (g)
M_i = initial moisture content
M_f = final or desired moisture content

All the physical properties were determined at four moisture contents and the mean values calculated for four replications at each moisture content level.

Dimensional properties determination

Grains were picked at random from the bulk grains and their principal dimensions being length (L), width (W) and thickness (T) measured with a micrometer screw gauge at 0.01mm accuracy.

Based on measurements of the length, width and thickness, data for the geometric mean diameter (Dg), surface area (S_a) and volume (V) were determined using the mathematical equations (2), (3) and (4), respectively.

$$D_g = (LxWxT)^{\frac{1}{3}} \quad (2)$$

$$S = \pi\left(D_g^{\,2}\right) \quad (3)$$

$$V = \frac{\pi}{6}\left(D_g^{\,3}\right) \quad (4)$$

1000 grain mass determination

Four replications of 100 grains were picked at random from each of the four samples and weighed on an electronic balance to 0.01g accuracy. The weight was then multiplied by 10 to give the 1000 grain mass and the average mass was recorded. Similar methods have been used by Wang *et al*. (2007) for Fibered Flaxseed; Tunde-Akintunde and Akintunde (2007) for beniseed; Tavakoli *et al.* (2009) for barley grains and Gharibzahedi *et al*. (2010) for pine nut.

Bulk density determination

The bulk density was determined using the standard test weight procedure. A standard container (beaker) of known weight and volume of 400ml was filled with grains from a height of 15cm at a constant rate. The grains were then levelled by striking off the top of the container. No additional manual compaction was done. The total weight of grains and cylinder was recorded. Bulk density was determined as the ratio of the mass of grains only to the volume occupied by the grains (volume of container). Similar methods have been used by Bart-Plange *et al*., (2005) for *'obatanpa'* maize variety and Baryeh (2000) for Bambara groundnuts.

True density determination

For true density, 100 grains were picked at random from each sample and the mass determined. Toluene was poured into a measuring cylinder and the volume recorded. The grains were then used to displace toluene in the measuring cylinder. The true density was found as an average of the ratio of the mass of grains to the volume of toluene displaced by grains. Toluene (C_7H_8) was used in place of water because it is absorbed by seeds to a lesser extent. Also, its surface tension is low, so that it fills even shallow dips in a seed and its dissolution power is low (Aydın, 2002 cited in Kabas *et al*., 2007; Demir *et al*., 2002 cited in Kabas *et al*., 2007).

Filling angle of repose determination

The angle of repose, has also been determined by other researchers such as Akaaimo and Raji, 2006 for Prosopis africana seeds and Ozturk *et al*., 2009, for Common Bean cv. 'Kantar-05' using a topless and bottomless cylinder.

In determining the filling angle of repose (θ_f) for '*asontem*', grains were poured from a height of 15cm unto a circular wooden plate of radius 10cm. The height of the heap was measured and the angle of repose was determined from the equations (5) and (6).

$$Tan\,\gamma = \frac{h}{r} = \frac{h}{10} \quad (5)$$

$$\gamma = tan^{-1}\frac{h}{r} \quad (6)$$

Where h, is height of the heap and r, is the radius of the plate.

Similar methods have been used by Bart-Plange and Baryeh (2002) for category B cocoa beans and Bart-Plange *et al*. (2005) for '*obatanpa'* maize variety.

Static coefficient of friction determination

The static coefficient of friction (μ) of the grains was determined against three structural surfaces namely; mild steel, plywood and rubber. The tilting table apparatus was used which includes the following; a frictionless pulley fitted on a frame, a PVC container and the testing surfaces.

A cylindrical PVC container, hollow at both ends of dimension 100mm diameter and 50mm height was filled with grains and lifted slightly about 2mm, so as not to touch the friction surface. The surface was gradually raised with a screw device until the cylinder along with the sample just begun to slide down. The angle of inclination which is the angle between the friction surface and the horizontal was read from the protractor. The coefficient of friction was calculated from equation 7.

$$\mu = \tan\theta \qquad (7)$$

Where μ = coefficient of static friction

θ = angle of tilt of table

Experimental design and data analysis

All tests were conducted at four levels of moisture content with four replications at each level. The experimental design used was the completely randomized design (CRD). Analysis of variance (ANOVA) was carried out on the data using Microsoft Excel version 2010 at a significance level of 5%. The Least Significant Difference (LSD) was determined where a significance difference existed between treatments means.

RESULTS AND DISCUSSIONS

Dimensional properties

As moisture content increased from 8.07% wb to 22.54% wb, length increased non-linearly from 7.00mm to 7.29mm, width from 6.27mm to 6.33mm and thickness from 4.54mm to 4.69mm and this can be found in Figures 1, 2 and 3. Length, width and thickness dimensions showed significant differences at 5%.

The increase in the linear dimensions can be attributed to the addition of moisture causing a volumetric expansion of the grains. Length had the highest increase in dimension of 4% from 4.54mm to 4.69mm, followed by thickness of 3% and then width of almost 1%.

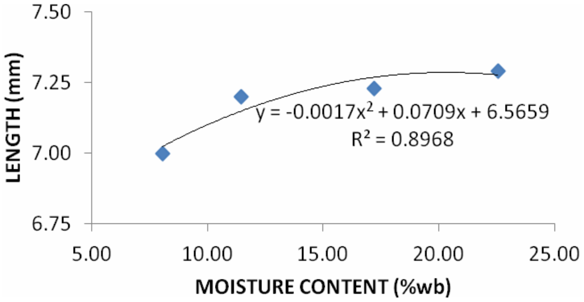

Figure-1. Variation of length with moisture content.

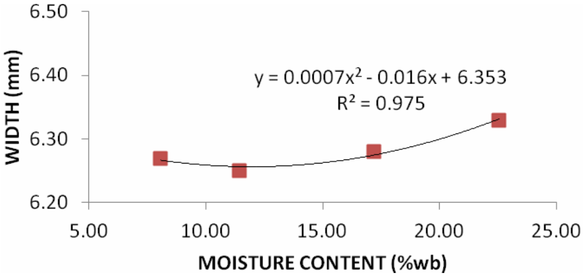

Figure-2. Variation of width with moisture content.

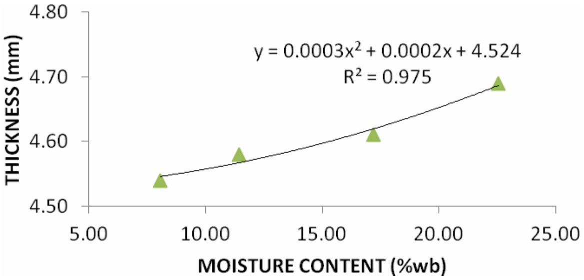

Figure-3. Variation of thickness with moisture content.

The relationship can be represented by the following equations;

$$L = -0.0017M^2 + 0.0709M + 6.5659 \qquad R^2 = 0.8968 \ (8)$$

$$W = 0.0007M^2 - 0.0161M + 6.3532 \qquad R^2 = 0.9758 \ (9)$$

$$T = 0.0003M^2 + 0.0002M + 4.5242 \qquad R^2 = 0.9750 \ (10)$$

The increasing trend in length, width and thickness have been reported by Deshpande *et al.* (1993) for soybean, Altuntas and Yildiz (2007) for faba bean, Ozturk *et al*. (2009) for common bean cv. 'Elkoca-05', Ahmadi *et al*. (2009) for fennel seeds and Gharibzahedi *et al*. (2010) for black cumin seeds.

Geometric mean diameter

Values for the geometric mean diameter increased for rewetting from 5.83mm to 5.99mm as shown in Figure-4. The equations describing rewetting trend is as follows:

$$D_g = 5.5368x^{0.0253} \qquad R^2 = 0.9754 \qquad (11)$$

Baryeh (2000) and Bart-Plange *et al*. (2006) found the geometric mean diameter of bambara groundnuts and maize to increase non-linearly with increasing moisture content respectively. Wang *et al.* (2007), Tavakoli *et al.* (2009) and Ozturk *et al.* (2009) found the geometric mean diameter to increase linearly with increasing moisture content for flaxseed, barley grains and common beans, respectively.

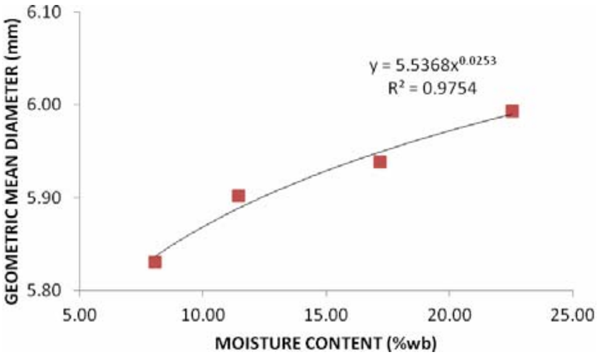

Figure-4. Variation of geometric mean diameter with moisture content.

Surface area

The surface area increased non-linearly from 107.03mm^2 at 8.07% wb to 113.09mm^2 at 22.54% wb during rewetting as shown in Figure-5. The increase in surface area during rewetting may be attributed to the increase in the three linear dimensions. Significant differences were recorded among all treatment means except at 17.20% wb and 22.54% wb ($P<0.05$).

The equation describing rewetting trend is as follows:

$$S_A = -0.0282M^2 + 1.2755M + 98.627 \qquad R^2 = 0.9987 \quad (12)$$

Deshpande *et al*. (1993), however, found the surface area of soybeans to increase linearly with grain moisture content and Baryeh (2000) reported a non-linear increase in surface area with increasing moisture content. Milani *et al.* (2007) reported an increased in surface area of cucurbit seeds.

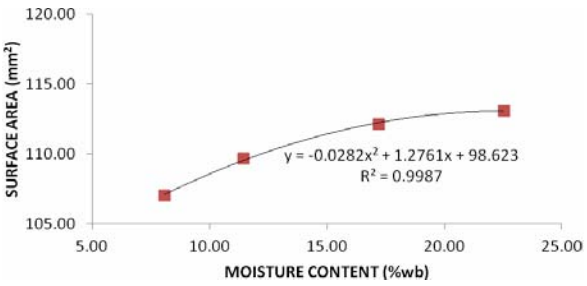

Figure-5. Variation of surface area with moisture content.

Volume

The volume was found to increase non-linearly with increasing moisture content as shown in Figure-6. Volume increased from 104.45mm^3 at 8.07% wb to 113.45mm^3 at 22.54% wb, representing an 8.62% increase to the initial volume.

The equations describing rewetting trend is as follows:

$$V = 8.1479\ln(x) + 87.71 \qquad R^2 = 0.9653 \qquad (13)$$

Baryeh (2000) and Baryeh (2002) also recorded an increase in volume with increasing moisture content for common beans and millet, respectively; likewise Ozturk (2009) for common beans cv. 'Elkoca-05', Igbozulike and Aremu (2009) for *Garcinia kola* seeds and Gharibzahedi *et al.* (2010) for black cumin (*Nigella sativa L.*) seeds.

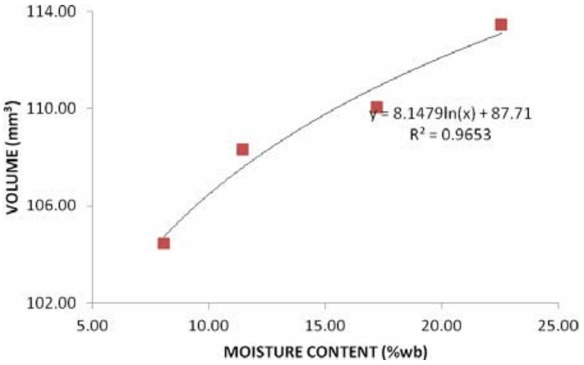

Figure-6. Variation of volume with moisture content.

1000 Grain mass

Figure-7 shows that the 1000 grain mass increased non-linearly with increasing moisture content. Rewetting from 8.07% wb to 22.54% wb caused an increase in mass from 120.15g to 130.58g. The variation in 1000 grain mass for rewetting can be expressed as follows:

$$1000_m = 0.0288M^2 - 0.2203M + 120.62 \quad R^2 = 0.9548 \quad (14)$$

The increase in mass could result from the addition of moisture content. A linear increase in 1000 grain mass has been recorded by Singh and Goswami (1996) for cumin; Sacilik *et al*. (2003) for hemp seeds; Wang *et al.* (2007) for flaxseed; Tavakoli *et al*. (2009) for barley grains and Gharibzahedi *et al.* (2010) for black cumin. Significant differences were found to exist among all the moisture content levels except at 11.45% wb and 17.20% wb.

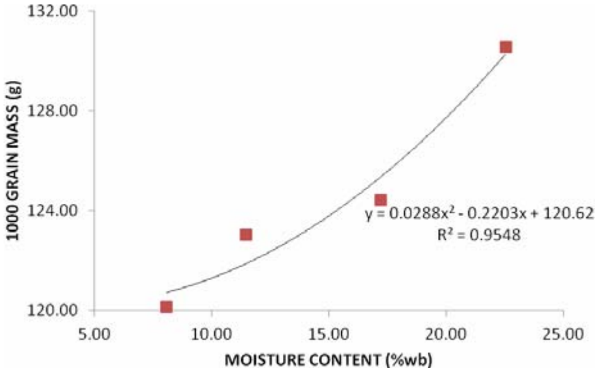

Figure-7. Variation of 1000 grain mass with moisture content.

Bulk density

During rewetting, bulk density values decreased non-linearly with increasing moisture content from 752.95kg/m^3 at 8.07% wb to 682.93kg/m^3 at 22.54% wb. The decrease in bulk density may be attributed to a higher volumetric increase resulting in more pore spaces between grains compared to an increase in mass; hence there are fewer grains occupying the same volume.

Figure-8 shows the variation of bulk density with moisture content and the relationship can be expressed as follows:

$$\rho_b = -0.219M^2 + 2.0307M + 749.24 \quad R^2 = 0.9927 \qquad (15)$$

Values for rewetting were found to be significantly different at 5%.

The decreasing trend of bulk density with increasing moisture content has been reported by Deshpande *et al*. (1993) for soybean within the moisture range of 8% db to 25% db; Tunde-Akintunde and Akintunde (2007) for beniseed in the moisture range of 3.5% db and 25.0% db; Ozturk *et al.* (2009) for new common bean cv. 'Elkoca-05' within the moisture range of 7.50% db and 19.85% db. On the other hand, an increase in bulk density as moisture content increases was reported by Joshi *et al*. (1993) for pumpkin seeds and Suthar and Das (1996) for karingda seeds. These discrepancies could be due to the cell structure, volume and mass increase characteristics of the grains and seeds as moisture content increases.

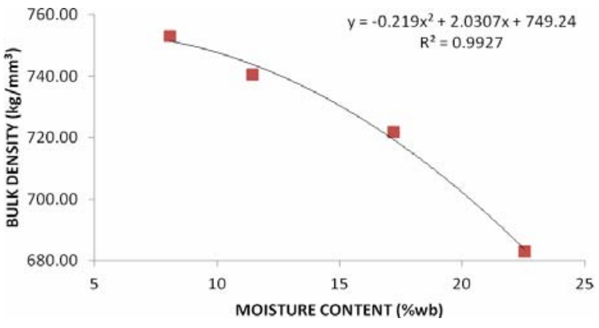

Figure-8. Variation of bulk density with moisture content.

True density

From Figure-9, it can be realized that an increase in moisture content led to a non-linear decrease in true density. True density decreased non-linearly with increasing moisture content from 1219.90 kg/m^3 to 1161.39 kg/m^3. The variation with moisture content for rewetting can be expressed as follows:

$$\rho_g = -0.222M^2 + 2.6995M + 1213.1 \quad R^2 = 0.9991 \qquad (16)$$

Rewetting values were not significant

The true density decreased with increasing seed moisture content as reported by Deshpande *et al.* (1993) for soybeans; Joshi *et al*. (1993) for pumpkin seeds; and Suthar and Das (1996) for karingda seeds. These seeds thus have lower weight increase in comparison to volume increase as their moisture content increase.

However, other researchers such as Singh and Goswami (1996) for cumin seeds; Gupta and Das (1997) for sunflower seeds and Wang *et al.* (2007) for flaxseed found the true density to increase with increasing moisture content.

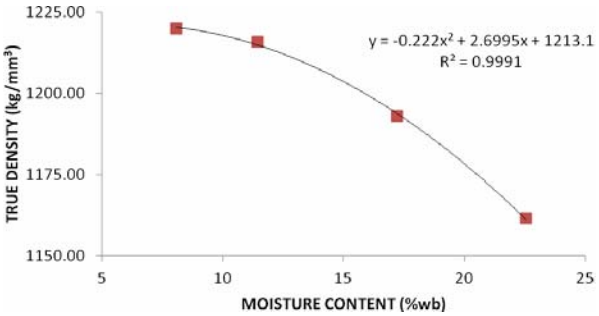

Figure-9. Variation of true density with moisture content.

Filling angle of repose

The filling angle of repose increased non-linearly with increasing moisture content as shown in Figure-10. The values for rewetting increased from a low of 27.81^0 at 8.07% wb to 32.31^0 at 22.54% wb.

The increase in filling angle may be due to an increase in surface roughness as well as size of individual grains which affect their ability to form a heap. The variation of the filling angle of repose with moisture content can be expressed as follows:

$$\Theta_f = 0.0063M^2 + 0.0945M + 26.867 \quad R^2 = 0.9599 \qquad (17)$$

Results obtained for rewetting showed significant difference at 5%. Significant differences were recorded among all the moisture levels.

Several researchers including Joshi *et al*. (1993) for pumpkin seeds; Singh *et al*. (1996) for cumin seeds; Suthar and Das (1996) for karingda seeds; Gupta and Das (1997) for sunflower seeds and Tavakoli *et al.* (2009) for barley grain have found the angle of repose to increase with increasing moisture content.

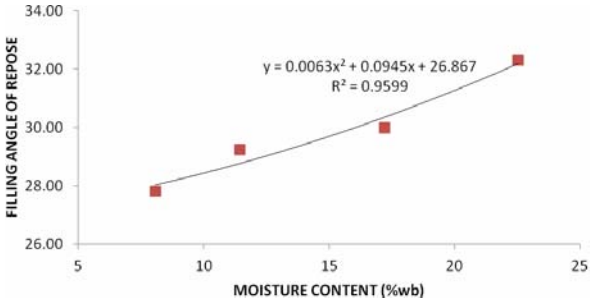

Figure-10. Variation of filling angle of repose with moisture content.

Coefficient of static friction

The variation of coefficient of static friction with moisture content on three surfaces namely mild steel, rubber and plywood are shown in Figure-11. The static coefficient of friction for rewetting increased non-linearly with increasing moisture content from 8.07% wb to 22.54% wb on all the three surfaces namely plywood (0.29 to 0.41), mild steel (0.31 to 0.45) and rubber (0.25 to 0.32). The coefficient of static friction for mild steel recorded the highest value followed by plywood and lastly rubber. The increasing coefficient may be due to smoother surface of rubber compared to plywood and mild steel. The increase in static coefficient of friction with increasing moisture content may be due to the increase in weight of grains from moisture absorption which reduces its ability to slide. The grains also possibly become rougher on the surface as the moisture content increases making the coefficient of friction increase.

Bart-Plange *et al.* (2005); Bart-Plange *et al.* (2006); Tavakoli *et al.* (2009); Ozturk *et al.* (2009) and Gharibzahedi *et al.* (2010) also found increasing linear relationships for cowpeas, maize, barley, common beans and black cumin grains respectively on plywood, rubber, glass, steel and galvanized iron sheet.

The variation with moisture content for plywood, mild steel and rubber can be expressed, respectively as follows:

$$\mu_p = 0.0011M^2 - 0.0242M + 0.4188 \quad R^2 = 0.9943 \qquad (18)$$

$$\mu_m = 0.0012M^2 - 0.0263M + 0.4394 \quad R^2 = 0.9956 \qquad (19)$$

$$\mu_r = 0.0004M^2 - 0.007M + 0.2864 \quad R^2 = 0.9977 \qquad (20)$$

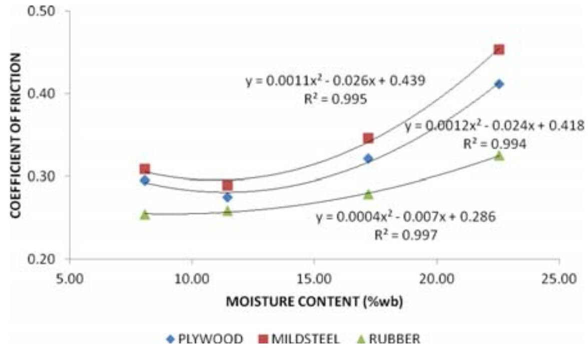

Figure-11. Variation of coefficient of static friction with moisture content for different surfaces.

CONCLUSIONS

The investigation of selected physical properties of '*Asontem*' cowpea variety revealed the following:

a) All linear dimensions, geometric mean diameter, surface area, volume and 1000 grain mass increased non-linearly with increasing moisture content;
b) The geometric mean, surface area and volume increased non-linearly with increasing moisture content during rewetting from 5.84mm to 5.99mm, 107.93mm^2 to 113.09mm^2 and 106.79mm^3 to 113.45mm^3, respectively;
c) The bulk density decreased non-linearly with increase in moisture content from 752.95 kg/m^3 to 682.93 kg/m^3;
d) The true density decreased non-linearly with increasing moisture content from 1219.90 kg/m^3 to 1161.39 kg/m^3;
e) The 1000 grain mass increased non-linearly from 120.15g to 130.58g during rewetting;
f) The filling angle of repose varied from 27.81 to 32.31 in the moisture range of 8.07% wb and 22.54% wb during rewetting; and
g) The static coefficient of friction for rewetting increased non-linearly with increasing moisture content from 8.07% wb to 22.54% wb on all the three surfaces namely plywood (0.29 to 0.41), mild steel (0.31 to 0.45) and rubber (0.25 to 0.32) during rewetting.

REFERENCES

Abatania L., Gyasi K. O., Coulibaly O., Adeoti R. and Salifu A. B. 2000. Adoption and impact of improved cowpea technologies in Ghana cited in Asafo-Adjei B., Atuahene A. G. and Singh B. B. 2005. Registration of 'Asontem' cowpea. International Institute of Tropical Agriculture. Crop Science Journal. (45): 26-49.

Ahmadi H., Fathollahzadeh H. and Mobli H. 2009. Postharvest physical and mechanical properties of apricot fruits, pits and kernels (C.V. Sonnati Salmas) cultivated in Iran. Pak J. Nut. 8(3): 264-268.

Akaaimo D. I. and Raji A. O. 2006. Some Physical and Engineering Properties of Prosopis Africana seed. Biosystems Engineering. 95(2): 197-205.

Altuntas E. and Yildiz M. 2007. Effect of moisture content on some physical and mechanical properties of faba bean (*Viciafaba* L.) grains. Journal of Food Engineering Research. 78: 174-183.

Asafo-Adjei B., Singh B. B. and Atuahen-Amankwah G. 2005. Registration of 'Asontem' Cowpea. Published in Crop Sci. 45: 26-49.

Aydın C. 2002. Physical properties of hazel nuts. Biosystem Engineering. 82(3): 297-303.

Bart-Plange A. and Baryeh E. A. 2002. The physical properties of Category B cocoa beans. Journal of Food Engineering. 60(2003): 219-227.

Bart-Plange A., Addo A. and Dzisi K. A. 2005. Effect of Rewetting and Drying on Selected Physical Properties of ‘Obatanpa’ Maize Variety. Journal of the Ghana Institute of Engineers. 3(1): 12-15.

Bart-Plange A., Addo A. and Dzisi K. A. 2006. Effects of Drying and Rewetting on Some Dimensional and Mass Properties of ‘Dorke’ Maize Variety. Journal of Ghana Science Association. 8(1): 89-96.

Baryeh E. A. 2000. Physical properties of Bambara Groundnuts. Journal of Food Engineering. 47(2001): 321-326.

Davis D. W., Oelke E. A., Oplinger E. S., Doll J. D., Hanson C. V. and Putnam D. H. 1991. Alternative Field Crops Manual. http://www.hort.purdue.edu/newcrop/afcm/cowpea.html

Demir F., Dogan H., Ozcan M. and Hacıseferogulları H. 2002. Nutritional and physical properties of hackberry (*Celtisaustralis* L.). Journal of Food Engineering. 54: 241-247.

Deshpande S. D., Bal S. and Ojha T. P. 1993. Physical properties of soybean. Journal of Agricultural Engineering Research. (56): 89-98.

Gharibzahedi S. M. T., Etemad V., Mirarab-Razi J. and Fos’hat M. 2010. Study on some engineering attributes of pine nut (Pinuspinea) to the design of processing equipment. (56) 3: 99-106.

Gharibzahedi S. M. T., Mousavi S. M., Moayedi A., Garavand A. T. and Alizadeh S. M. 2010. Moisture-dependent engineering properties of black cumin (*Nigella sativa* L.) seed. AgricEngInt: CIGR. 12(1).

Gupta R. K. and Das S. K. 1997. Physical properties of sunflower seeds. Journal of Agricultural Engineering Research. (66): 1-8.

Igbozulike A. O. and Aremu A. K. 2009. Moisture dependent physical properties of Garcinia kola seeds. Journal of Agricultural Technology. 5(2): 239-248.

Joshi D. C., Das S. K. and Mukherji R. K. 1993. Physical properties of pumpkin seeds. Journal of Agricultural Engineering Research. (54): 219-229.

Kabas O., Yilmaz E., Ozmerzi A. and Akinci I. 2007. Some physical and nutritional properties of cowpea seed (*Vigna sinensis* L.). Journal of Food Engineering. 79: 1405-1409.

Kiliçkan A., Üçer N. and Yalçin I. 2010. Some physical properties of spinach (*Spinacia oleracea* L.) seed. African Journal of Biotechnology. 9(5): 648-655.

Milani E., Seyed M., Razavy A., Koocheki A., Nikzadeh V., Vahedi N., MoeinFard M. and Gholamhossein Pour A. 2007. Moisture dependent physical properties of cucurbit seeds. Int. Agrophysics. 21: 157-168.

Ozturk I., Kara M., Elkoca E. and Ercisli S. 2009. Physico-chemical grain properties of new common bean cv. ‘Elkoca-05’ Scientific Research and Essay. 4(2): 88-93.

Sacilik K., Öztürk R. and Keskin R. 2003. Some physical properties of hemp seed. Bios stems Engineering. 86(2): 191-198.

Singh K. K. and Goswami T. K. 1996. Physical properties of cumin seed. Journal of Agricultural Engineering Research. (64): 93-98.

Stroshine R. and Hamann D. 1995. Physical Properties of Agricultural Materials and Food Products. Course Manual, Purdue University, Indiana.

Suthar S. H. and Das S. K. 1996. Some physical properties of karingda [citrulluslanatus (thumb) mansf] seeds. J. Agric. Eng. Res. 65(1): 15-22.

Tavakoli M., Tavakoli H., Rajabipour A., Ahmadi H. and Gharibzahedi S. M. T. 2009. Moisture-dependent physical properties of barley grains. International Journal of Agricultural and Biological Engineering. 2(4).

Tunde-Akintunde T. Y. and Akintunde B. O. 2007. Effect of Moisture Content and Variety on Selected Properties of Beniseed. Agricultural Engineering International: The CIGRE journal. Manuscript FP 07 021. Vol. IX.

Varnamkhasti M. G., Mobli H., Jafari A., Rafiee S., Soltanabadi M. H. and Kheiralipour K. 2007. Some Engineering Properties of Paddy (var. sazandegi). International Journal of Agriculture and Biology. http://www.fspublishers.org

Wang B., Li D., Wang L., Huang Z., Zhang L., Chen X. D. and Mao Z. 2007. Effect of Moisture Content on the Physical Properties of Fibered Flaxseed. International Journal of Food Engineering. 3(5).